BASES OF METEOROLOGY

Makra László

HSTORICAL OVERVIEW - ANTIQUITIES

- Early observations of atmospheric phenomena
  Chinese, Indian, Sumerian, Incan, Mayan civilizations → Arabic mediation

GREECE

- Hyppocrates (460-377 BC):
  one of the founders of the ancient medical science
  medical meteorology (hyppocratesi oath);

- Ptolemaios (2nd decade AD):
  geocentric world view;
  „Almagest" – his major work in Arabic language;

- Origin of the word „meteorology”:
  - Aristotle (384-322 BC):

    „Meteorologica” (this is the only known professional work until the Middle Ages)

    „meteorosz" = between heaven and earth; „logosz” = science

- The subject of meteorology:
  - in anceint times
  - nowadays

- Words of Greek origin in meteorology:

  cosmos, astronomy, sphere, atom, atmosphere, homo-, heterosphere, tropo-, strato-, mezo-, thermo-, exo-, criosphere, magnetosphere, homogeneous, heterogeneous, baro-, baric, isobar, isotherm, cyclone, anticyclone, dynamics, statics, synoptic, aerology, climatology, geology, geography, …

The place of meteorology among the sciences

NATURAL SCIENCES

M A T H E M A T I C S

BIOLOGY CHEMISTRY PHYSICS **G E O S C I E N C E S**

Geology Oceanology Hidrology Geochemistry Geophysics **Geography**

M E T E O R O L O G Y

Theoretical or Dynamic meteorológy

Synoptic meteorológy

Cosmic meteorology

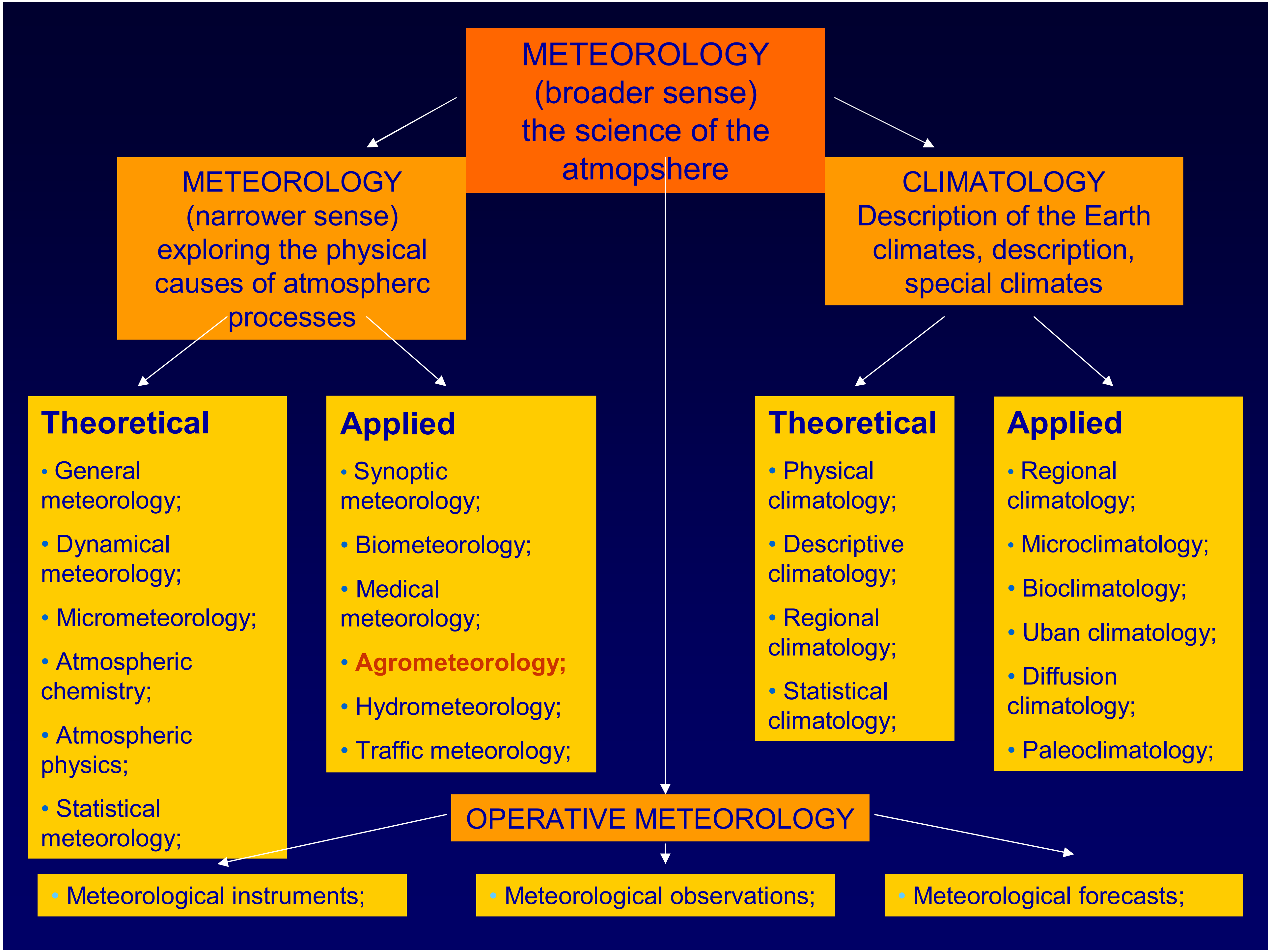
Aerology

General or Physical

Bio- and agro-meteorology

Hydro-meteorology

Climatology


METEOROLOGY (broader sense) the science of the atmopshere
METEOROLOGY (narrower sense) exploring the physical causes of atmospherc processes
CLIMATOLOGY Description of the Earth climates, description, special climates
Theoretical
• General meteorology;
• Dynamical meteorology;
• Micrometeorology;
• Atmospheric chemistry;
• Atmospheric physics;
• Statistical meteorology;
Applied
• Synoptic meteorology;
• Biometeorology;
• Medical meteorology;
• Agrometeorology;
• Hydrometeorology;
• Traffic meteorology;
Theoretical
• Physical climatology;
• Descriptive climatology;
• Regional climatology;
• Statistical climatology;
Applied
• Regional climatology;
• Microclimatology;
• Bioclimatology;
• Uban climatology;
• Diffusion climatology;
• Paleoclimatology;
OPERATIVE METEOROLOGY
• Meteorological instruments;
• Meteorological observations;
• Meteorological forecasts;

The atmosphere of the Earth

Definition:

The atmosphere is a gas shell belonging to several planets in the solar system.

The atmosphere of the Earth

- the composition of the atmosphere
- the extension of the atmosphere
- the mass of the atmosphere
- the structure of the atmosphere

▪ The composition of the atmosphere

The atmosphere of the Earth = dispersed system of gas mixture + liquid + solid materials

Classification criteria of the atmospheric gases:

1. how constant is the amount of the given gas in space and time;

   1a. Permanent gases (N_2, O_2 and noble gases): their quantity is unchanged for a long time (not in geological time scale!);

   1b. Changing gases (CO_2, CH_4, H_2, N_2O, O_3): their quantity changes in a shorter period of time (within a few years, a few decadees) and concentrations vary spatially;

   1c. Highly variabel gases (CO, NO_2, NH_3, SO_2, H_2S): their amount greatly changes in a very short period of time (within a few days or weeks) and over a small area.

2. relative quantity (volume ratio) of the atmospheric gases

2a. main components (N_2, O_2, CO_2, Ar: 99,998 %);

2b. trace gases (all remaining gases besides 2a);

2c. solid and liquid particulates

2b. + 2c. = trace materials (the most important of them are: H_2O and particulates)

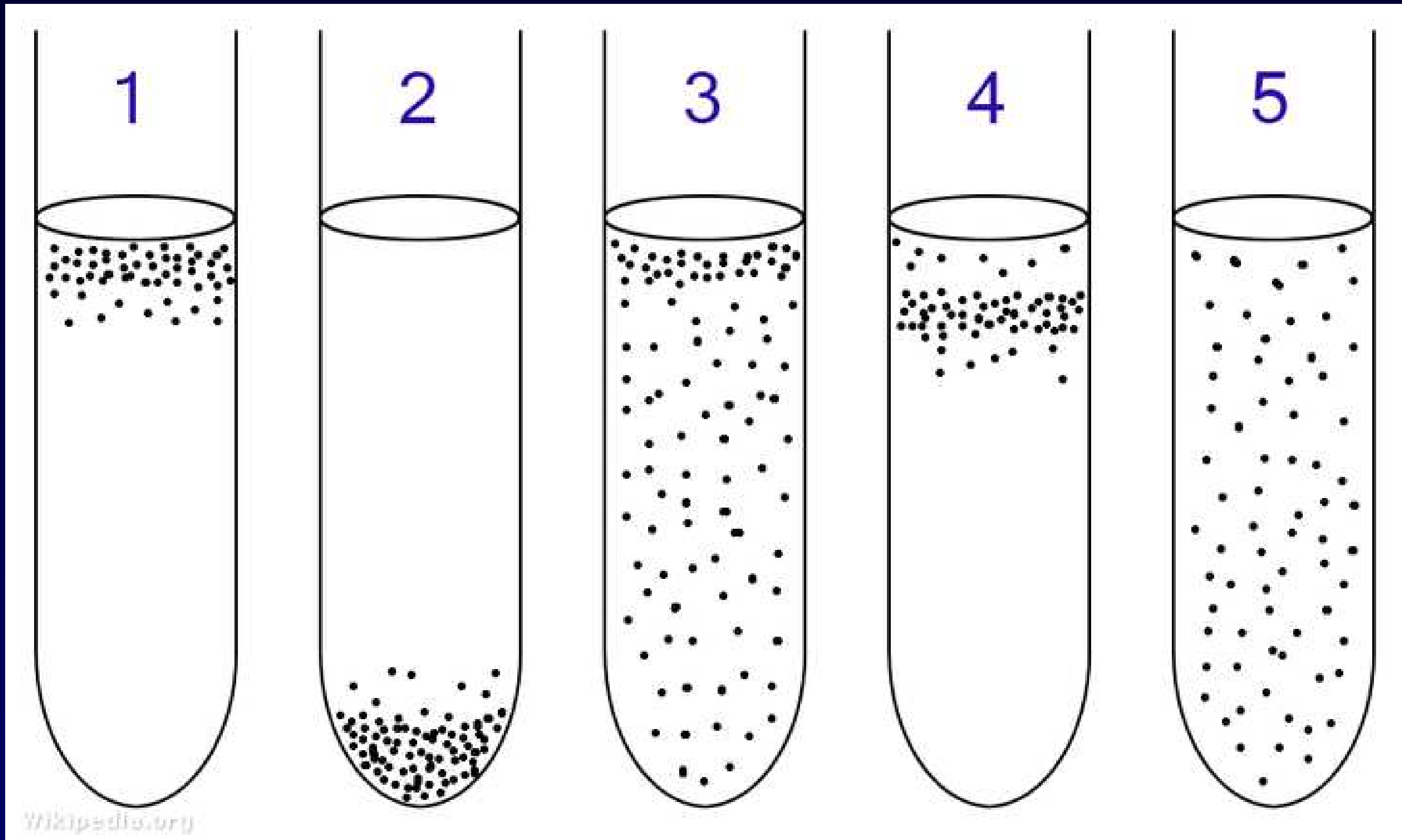
Aerosols form a dispersed system in the flowing air in which the gaseous medium comprises finely dispersed liquid or solid particles. The particle size range is of 10 nm - 500 nm. Solid material is called smoke, while if the spray (or condensed) material is liquid, it is called fog. The cloud is formed of natural aerosols.

Anaerobic environment ⟶ aerobic environment

Without cyanobacteria there would be no life on Earth ⟷ due to them almost all life extincted on the Earth billions of years ago;

Cyanobacteria first appeared on Earth with approx. the first O_2 molecules. They are unicellular, without nucleus – however, they played a major role in developing the current wildlife of the Earth.

The main components of the primary atmosphere of the Earth: N_2, CO_2, CH_4. It hardly contained O_2.
Anaerobic (oxygen-free) micro-organisms (ancestors of cyanobacteria) of the ancient ocean came to the surface approx. 2.5-3.5 billion years ago $\Rightarrow$ sunlight $\Rightarrow$ photosynthesis.



Location of cultured bacteria on liquid media, in relation to the oxygen:
1: Obligate aerobic 2: Obligate anaerobic 3: Facultative anaerobic
4: Microaerophilic 5: Aerotolerant

cyanobacteria:

photosynthesis ⇒ $CO_2 + H_2O \rightarrow C_6H_{12}O_6$ (glucose and fructose) + O_2 .

That is: $6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$

Sugar: energy + evolutionary advantage ⇒ they overgrew all other types of bacteria in the oceans + lots of O_2 formed.

But: O_2 then was a toxic metabolite (corrosive gas, such as fluorine).

Approx. 3 billion years ago: as a metabolite of certain plant cells, life first formed oxygen ⇒ the deadly poison for the environment.

At first, the oxygen produced was absorbed by ferrous rocks and decaying organic matters, **though:** a few hundred million years later ⇒ O_2 has accumulated in the atmosphere.

For the remaining single-celled $\longrightarrow$ this is ecological disaster;

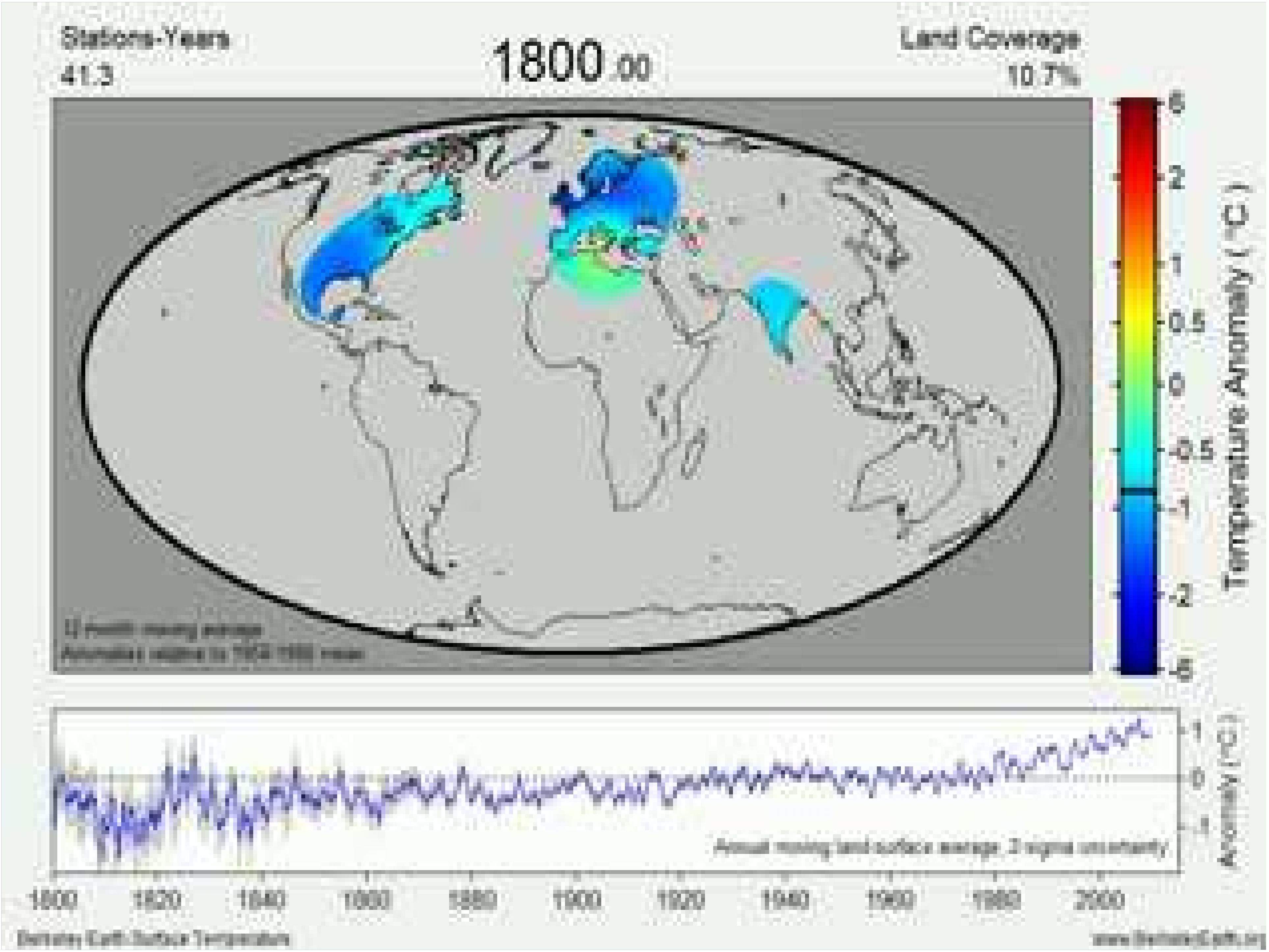
$\Rightarrow$ 2.5 billion years ago O_2 destroyed to almost every living being (oxygen disaster);

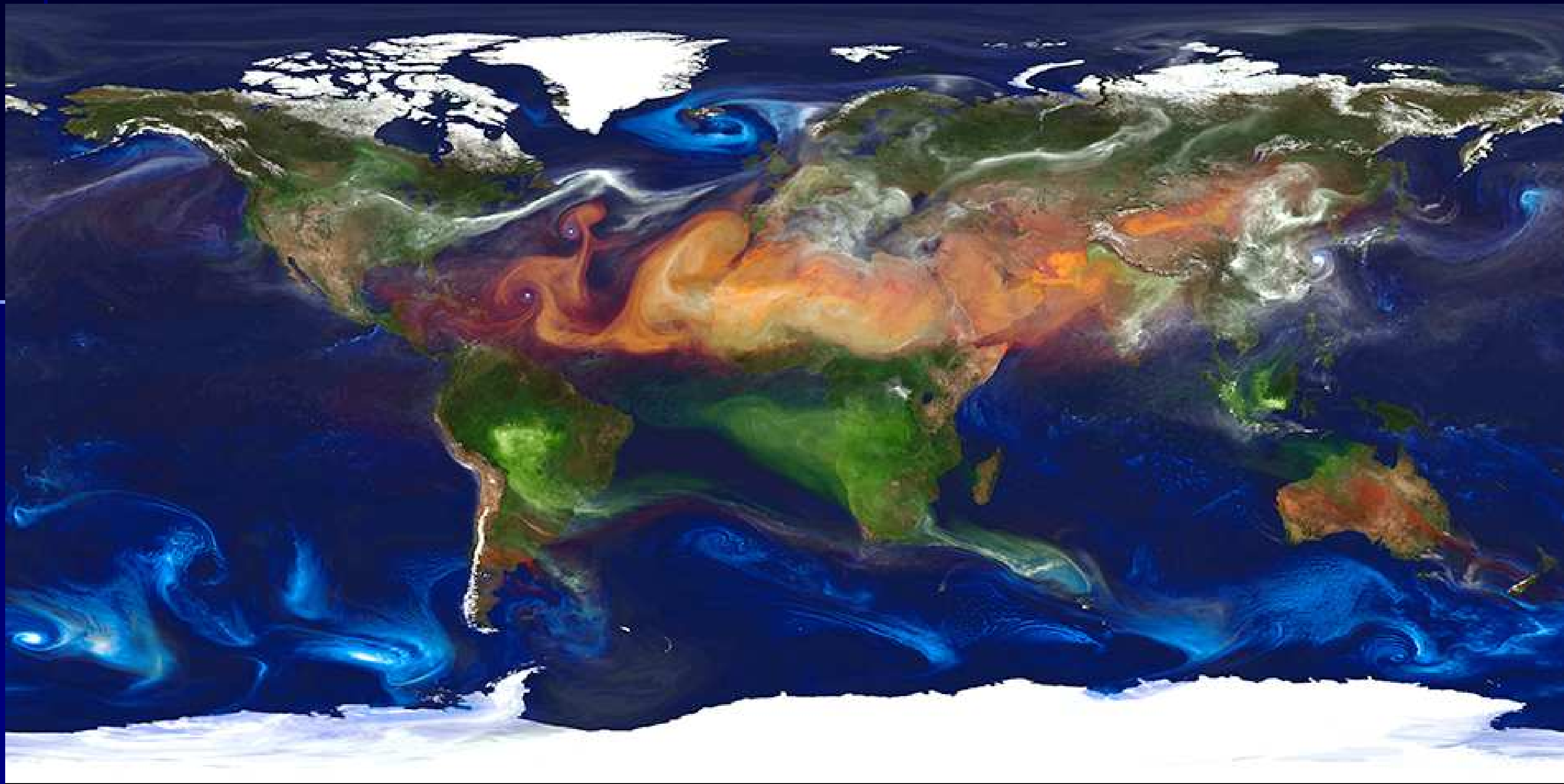
Primary atmosphere: lots of CH_4 $\Rightarrow$ high greenhouse effect;

But: $CH_4 + O_2 \longrightarrow CO_2 + H_2O$ $\Rightarrow$ greenhouse effect reduces $\Rightarrow$ the Earth's atmosphere has cooled („huroni" Ice Age: began 2.4 billion years ago, lasted ≈300 million years;

living conditions have changed $\Rightarrow$ aerobic organisms began to absorb atmospheric O_2 $\Rightarrow$ great energy for them $\Rightarrow$ it promotes evolution.
$\Rightarrow$ In the oceans bigger and bigger bacteria $\Rightarrow$ devoured the cyanobacteria;
$\Rightarrow$ + cyanobacteria $\Rightarrow$ photosynthesis in new bacteria, as well;

$\Rightarrow$ from the resulting hybrid from the two types of bacteria: **first plant cells**.
Cyanobacteria still exist, can be found everywhere:
O_2: $\longrightarrow$ atmosphere;
N_2: $\longleftarrow$ atmosphere + soil;
$\Rightarrow$ $NH_3 \longrightarrow$ fertilizer raw material;
$\Rightarrow$ **useful, without them there would be no life on Earth;**


Stations-Years
41.3
1800.00
Land Coverage
10.7%
5
2
1
0.5
0
-0.5
-1
-2
-5
Temperature Anomaly (°C)
1
0
-1
Anomaly (°C)
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000



GEOS-5 simulation,
NASA Center for Climate Simulation at Goddard Space Flight Center, Greenbelt, Md.,
Goddard Earth Observing System Model,
resolution: 10 km

red: dust rising from the surface;
blue: sea salt particles swirling in cyclones;
green: smoke rising from fires;
white: sulfate particles from volcanic activities and fossil fuels;

Composition of the atmosphere

Residence time: $\tau = M / F = M / R$ **where M is the amount of a given gas, F (R) formation (absorption) rate [tonnes / year].**

összetevő	Térf.%	ppm	Tartózkodási idő
Állandó összetevők			
▪ **nitrogén N_2**	78,084		10^6 év
▪ **oxigén O_2**	20,947		$5 \cdot 10^3$ év
▪ **argon Ar**	0,934		∞
▪ neon Ne		18,18	∞
▪ hélium He		5,24	∞
▪ kripton Kr		1,14	∞
▪ xenon Xe		0,087	∞
Változó összetevők			
▪ **szén-dioxid CO_2**		354	15 év
▪ metán CH_4		2,0	4 év
▪ hidrogén H_2		0,5	6,5 év
▪ dinitrogén-oxid N_2O		0,31	8 év
▪ ózon O_3		0,04	~2 év
Erősen változó összetevők			
▪ szén-monoxid CO		0-0,05	~0,3 év (100 nap)
▪ Vízgőz H_2O	0-4		10-14 nap
▪ Nitrogén-dioxid NO_2		0-0,003	~6 nap
▪ Ammonia NH_3		0-0,02	~7 nap
▪ Kén-dioxid SO_2		0-0,002	~4 nap
▪ Kén-hidrogén H_2S		0-0,003	~2 nap

underlined: main components; framed: greenhouse gases;

Extension of the atmosphere

- ✓ Lower and upper boundaries can not be accurately tightened.
- ✓ The lower limit of the atmosphere:

  surface of the liquid and the. The soil surface is not automatically a limit: cavities and caves in the soil are also filled in with air.

- ✓ The upper limit of the atmosphere :

  The upper limit of the atmosphere:
  Theoretically: equilibrium of the centrifugal and gravitational force (G = Fc) calculated in a coordinate system fixed to the Earth can be observed at h = 36,000 km altitude. Utnil this height the gas shell moves with the Earth.

- **Empirically**: evidences for estimating the extent of the atmosphere:

  1. The first flash of meteorites:

     Reason: friction;

     Discoverable: approx. At height of 100 km, but also at height of 300-500 km!

  2. The aurora:

     Reason : hydrogen nuclei and electrons from the sun induce gas atoms high in the atmosphere.

     Discoverable: 60-400 km, 1,000 km altitude!

  3. Radio wave refletions:

     Reason : the high-altitude ionized (electrically conducting) layers, where a portion of the gas atoms are electrically charged due to the sun's ultraviolet and X-ray radiation.

     Discoverable: at 60-300 km, but also at a height of 3000 km!

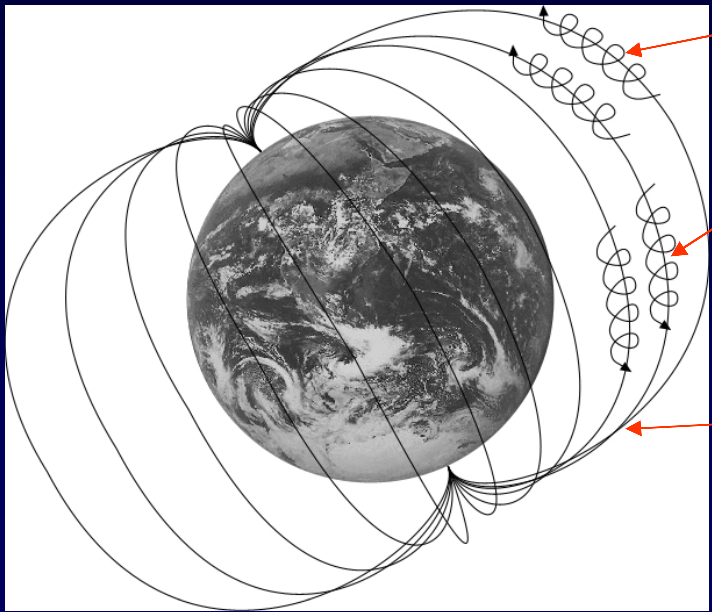





First flash of meteorites

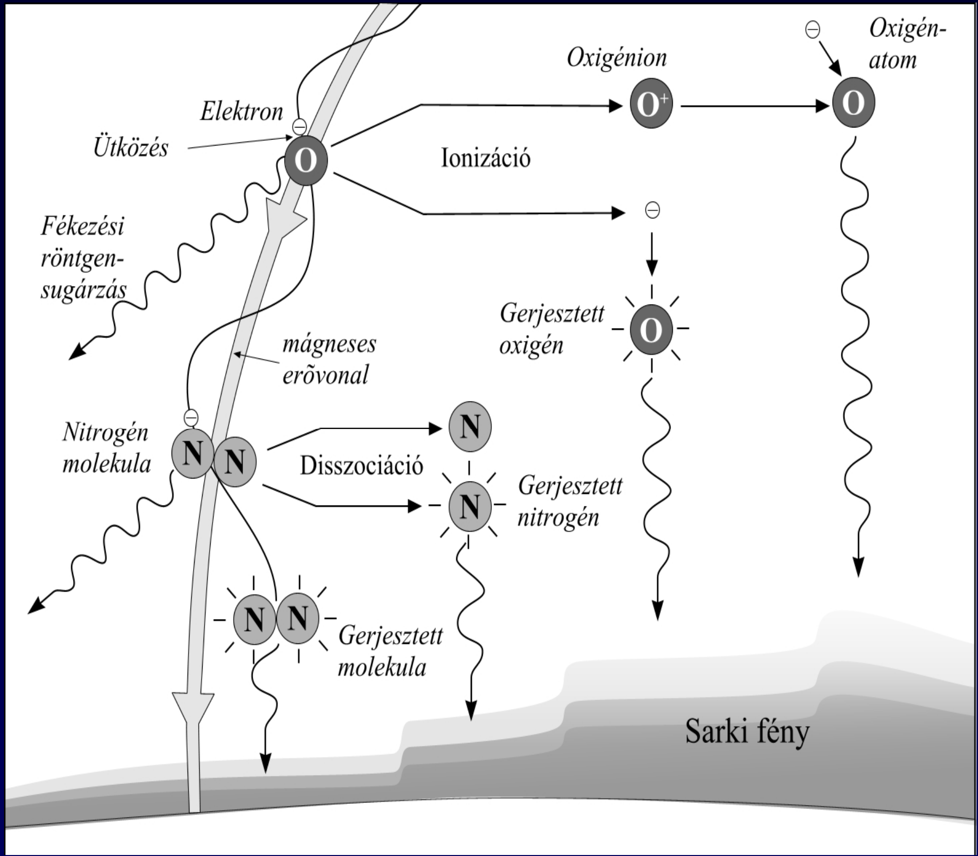
Antarctica meteorite (identifier: ALH84001,0).
August 7, 1996, NASA: traces for evidence of life.

Aurora borealis I.



Electrically charged particles

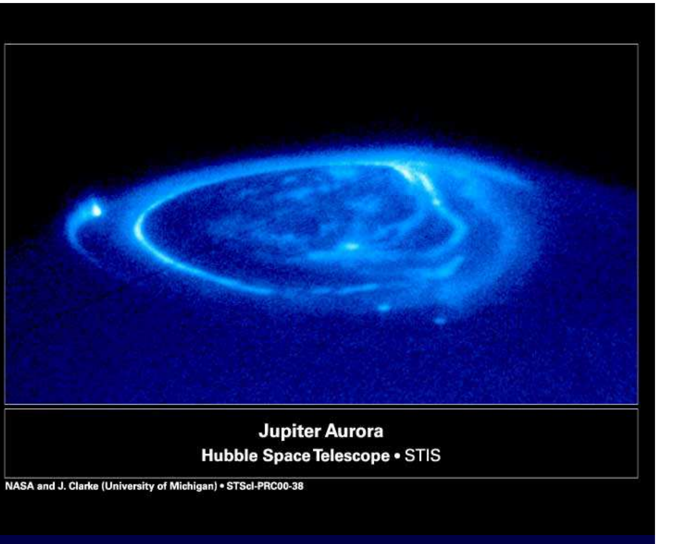
Magnetic lines of force



Aurora borealis II.

Aurora borealis III.

On Jupiter



On Earth

Aurora borealis IV.

Anchorage, Alaska

Aurora borealis V.

Jökulsárlón glacier lake, Iceland

Photo: Vetter S.

The mass of the atmosphere

- it can be determined on surface air pressure

$$G = m \cdot g$$

$$F = p \cdot A$$

$$m \cdot g = p \cdot A$$

$$\Rightarrow \quad m = \frac{p \cdot A}{g}$$

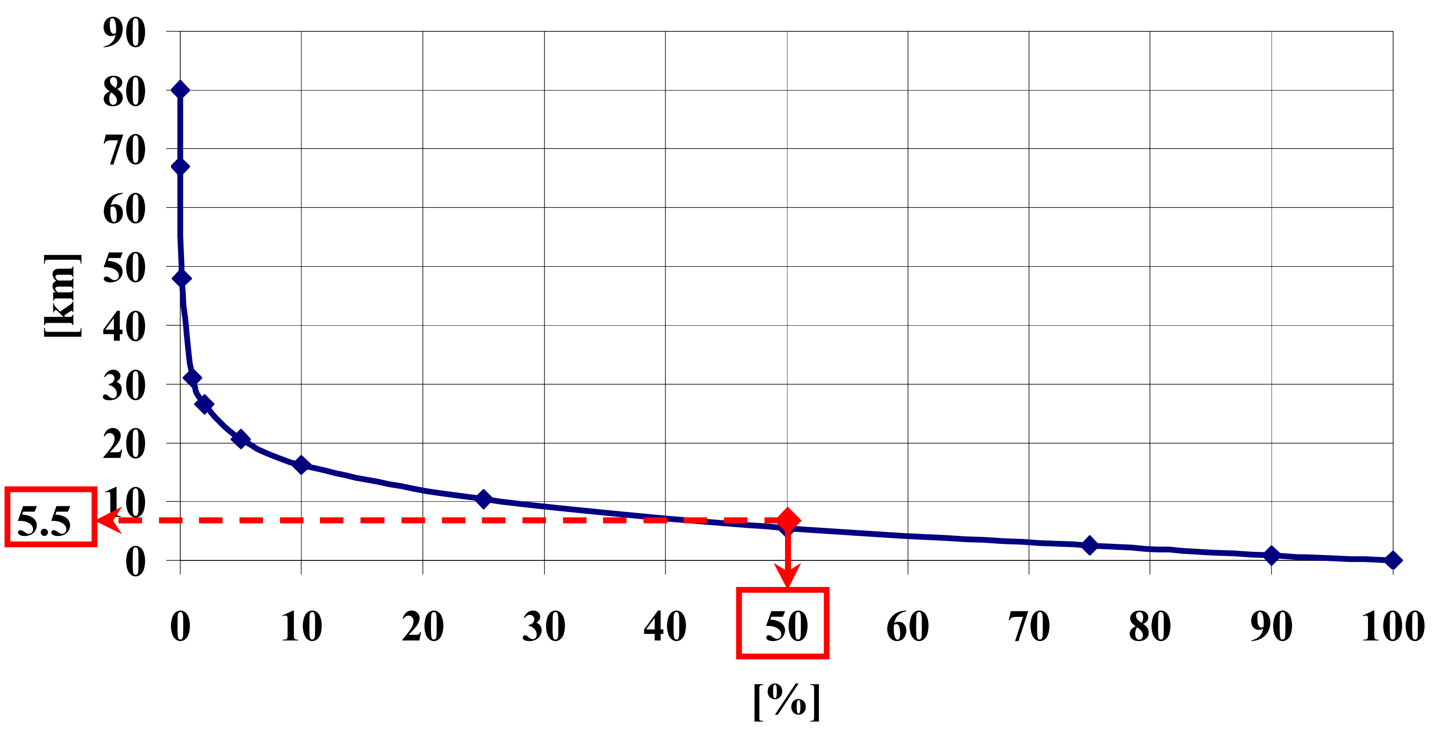
$$\left[\frac{N \cdot m^{-2} \cdot m^{2}}{m \cdot s^{-2}}\right] \rightarrow \left[kg \cdot m \cdot s^{-2} \cdot m^{-2} \cdot m^{2} \cdot m^{-1} \cdot s^{2}\right] \rightarrow [kg]$$

Some calculations:

Aujeszky (1952): 5,275 * 10^{21} g
Rákóczi (1980): 5,196 * 10^{21} g
Makra (1995): 5,136 * 10^{21} g
Trenberth (1981): 5,117 * 10^{21} g

- A significant proportion of the mass of the atmosphere is found in the lower 20 km layer.

Distribution of the atmosphere according to altitude



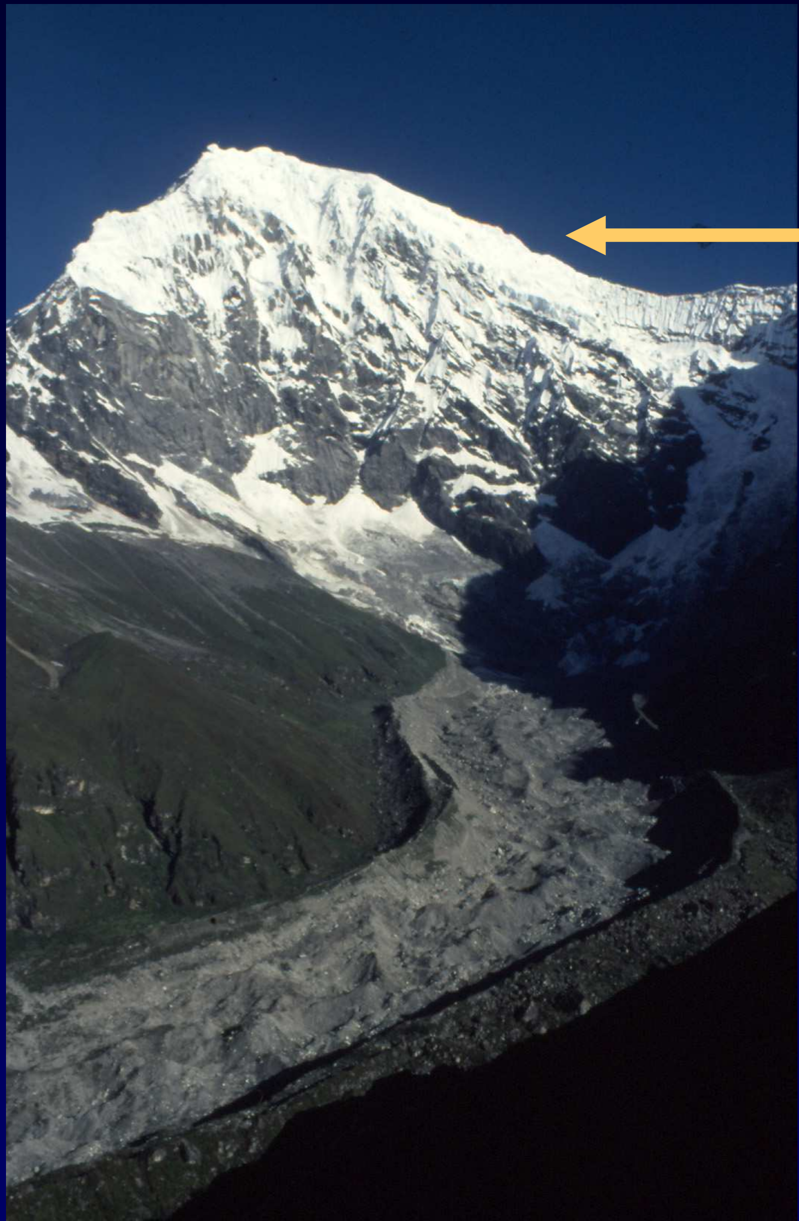
Distribution of the atmosphere according to altitude

50 %: below 5.5 km

90 %: below 16.2 km

95 %: below 20.6 km

99 %: below 31.0 km



Langtang Lirung, High Himalayas, Nepal, July 1993

Yala peak, 5500 m, Langtang Lirung (background), High Himalayas, Nepal, July 1993

Yala peak, 5500 m, Langtang Lirung (background), High Himalayas, Nepal, July 1993

✓ homogeneous atmosphere

Determine the thickness of a homogeneous atmosphere!

$$G = F$$

$$m \cdot g = p \cdot A$$

$$\rho \cdot V \cdot g = p \cdot A$$

$$\rho \cdot A \cdot h \cdot g = p \cdot A$$

$$\rho \cdot h \cdot g = p$$

$$h = \frac{p}{\rho \cdot g}$$

$$[h] \quad \left[\frac{N \cdot m^{-2}}{kg \cdot m^{-3} \cdot m \cdot s^{-2}}\right] \rightarrow \left[kg \cdot m \cdot s^{-2} \cdot m^{-2} \cdot kg^{-1} \cdot m^{3} \cdot m^{-1} \cdot s^{2}\right] \rightarrow [m]$$

The structure of the atmosphere

Chemically

- homosphere
- heterosphere

Physically

Based on temperature

Troposphere
(0 km < h < 20 km); t ≈ -50, -60°C;

Stratosphere
(20 km < h < 50 km); t ≈ -0°C;

Mesosphere
(50 km < h < 80 km); t ≈ -100°C;

Thermosphere
(h < 1000 km); t ≈ -1000°C;

Exosphere

Based on air electricity

A series of ionizing layers → **Ionosphere**

D layer: 70-90 km daytime;

E-layer: 90-140 km daytimel;

sporadic E: irregularly

F layer: above 140 km; constant, splits in daytime: ***F1, F2;***

G layer: above 400 km;

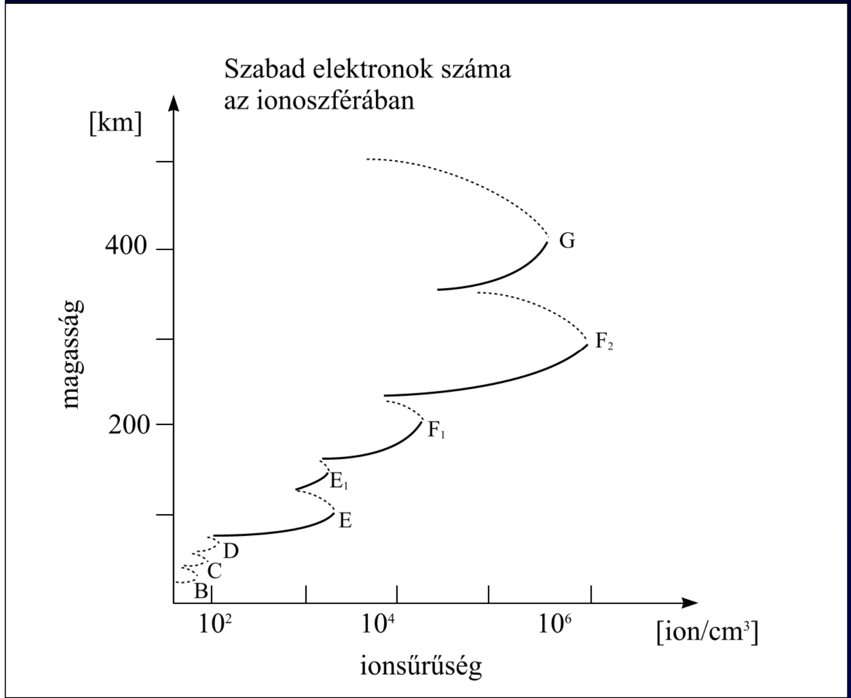
Based on magnetism

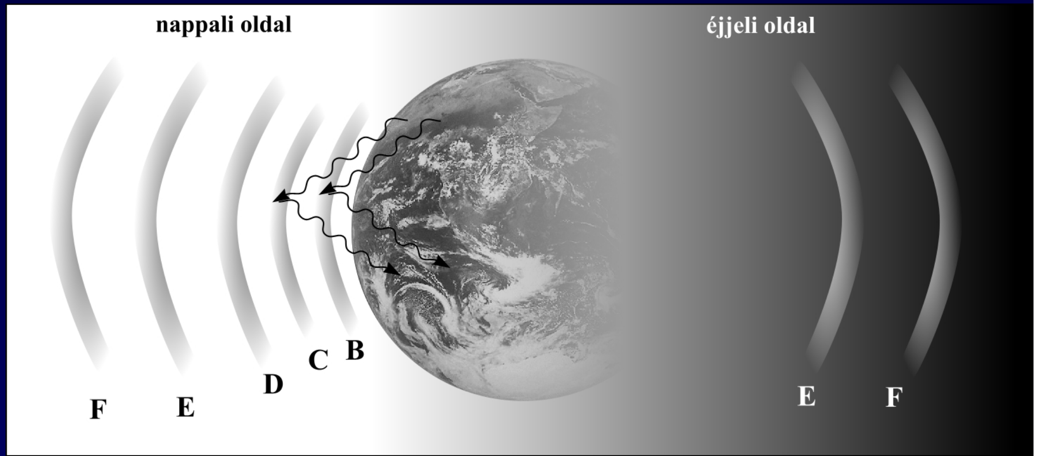
If h < 80 km:
⇒ the magnetic field of the Earth does not affect the atmosphere;

If (80 km < h < 140 km:
⇒ **atmospheric dynamo zone;**

If h > 140 km:
⇒ **magnetosphere**

Ionosphere





Position of the ionized layers, the distribution of concentrations of free electrons in the atmosphere

The position of the main layers of the Ionosphere

▪ The structure of the atmosphere

- Based on the chemical composition and the average molecular weight of the gases in the atmosphere:

  1. homosphere: chemical compsition and the average molecular weight of the gases is constant ($h \leq 90$ km);
     reason: atmospheric mixing movements;

  2. heterosphere: chemical composition is the function of the height, and the average molecular weight of the gases rapidly decreases up to the height ($h > 90$ km);

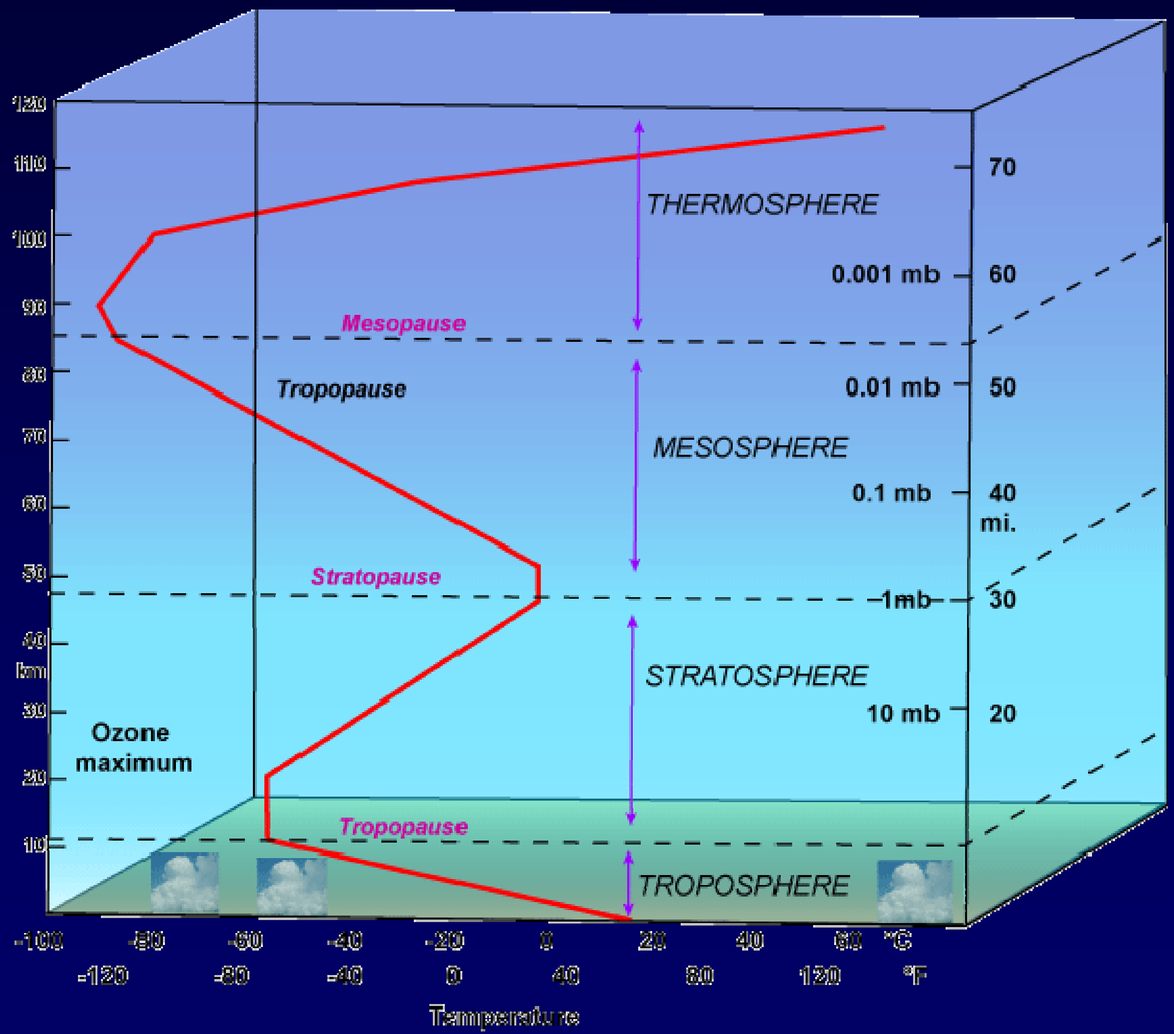
     $\Rightarrow$ components with lower density:

     800-1000 km: O

     1500 km: He

     $>$ 1500 km: H_2

- Based on the thermal properties of the atmosphere:



- Structure according to temperature

troposphere (upflow spherical shell): [0 km – 10-15 km]
stratosphere (layered spherical shell): [10-15 km – 50 km]
mezosphere (middle spherical shell): [50 km – 90 km]
termosphere (hot spherical shell): [90 km – 1.000 km]
magnetosphere (magnetic spherical shell): [1.000 km – 60.000 km]
exosphere (outer spherical shell) [60.000 km –]

- Troposphere
  - ✓ the upper limit from the surface: 8 km < h < 18 km;
  - ✓ mean elevational change of the temperature: -0,65 °C / 100 m (weekly unstable air conditions);

Reason:

Solar radiation heats the Earth from the surface.

Consequence:

- ➢ water-related phenomena in the atmosphere;
- ➢ weather conditions;

Characteristics of the standard atmosphere (ICAO, (International Civil Aviation Organization), φ = 45°

- Mean sea level pressure: **p_o= 1013.25 mb;**
- Absolute max/min: **p_{max} =** 1079 mb**, p_{min} =** 877 mb;
- Temperature gradient in the troposphere: **-0.0065 $K \cdot m^{-1}$**;
- Temperature at sea level: **15°C (288,16 K)**;
- Average molecular weight: 28.9644 $kg \cdot mol^{-1}$;
- Density at sea level: 1.225 $kg \cdot m^{-3}$;
- Universal gas constant: 8314.32 $J \cdot mol^{-1} \cdot K^{-1}$;

- Tropopause

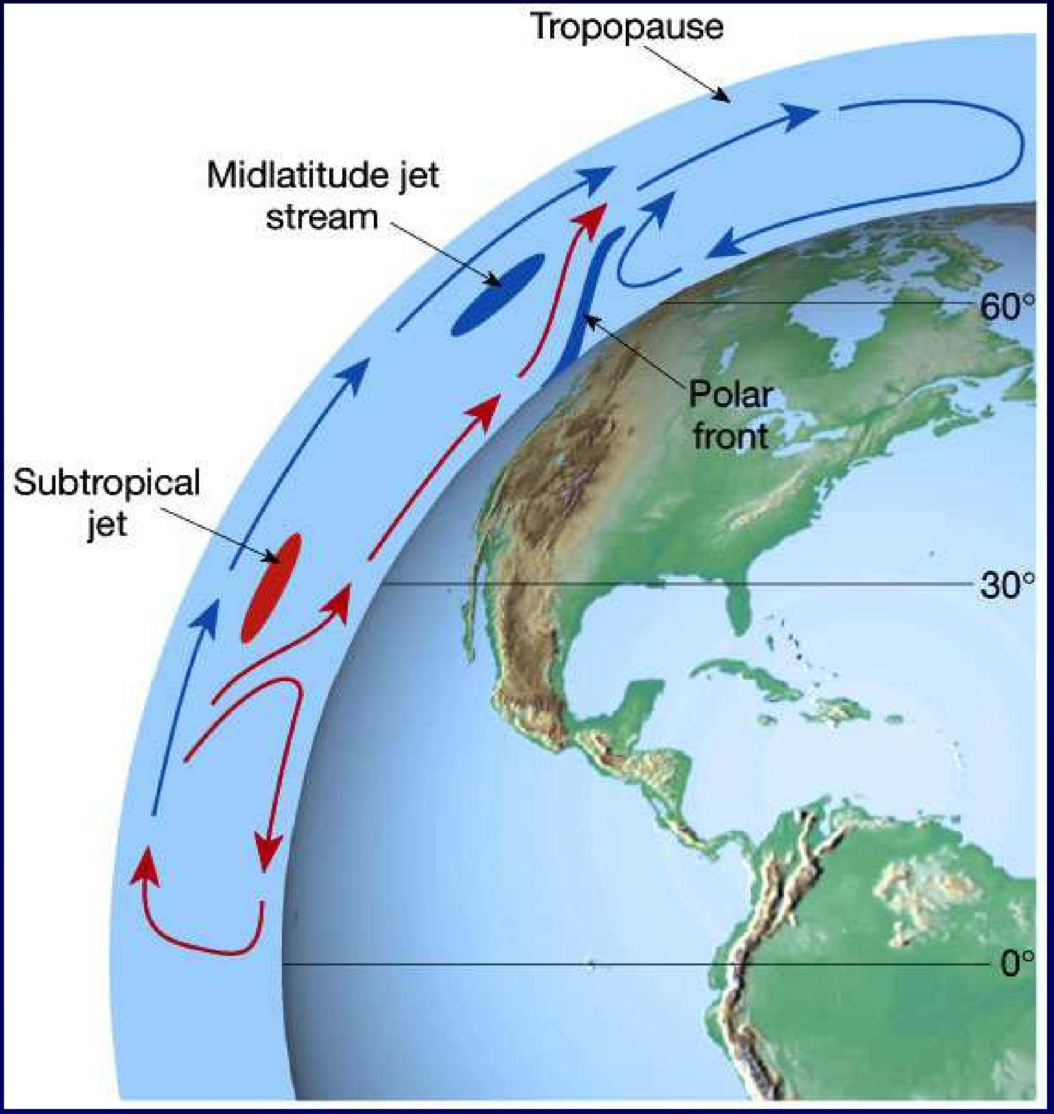
  - ✓ at the top of the troposphere isothermia;

    $\Rightarrow$ temperature gradient = 0.

    $T_{mean} \approx -56\ ^{o}C$;
  - ✓ h (tropopause) = f (φ; season);
  - ✓ tropopause „break”: when air masses with different characteristics meet

    $\Rightarrow$ jet stream ($v \approx 200\ km \cdot h^{-1}$);

Jet-stream



Tropopause
Midlatitude jet stream
Subtropical jet
Polar front
60°
30°
0°

- Stratosphere
  - ✓ The temperature increases with height (h > 20 km); temperature inversion;
  - ✓ ⇒ no vertical air movements;
    reason: ozone in the stratosphere (UV-absorbing ⇒ warming effect);
  - ✓ cc_{max} (O_3) ≈ 25 km and T_{max} ≈ 50 km;
    reason: the number of molecules is less at 50 km;
    - ➢ the absorbed energy increases more rapidly the temperature of less number of molecules;
    - ➢ more energy is absorbed from solar radiation at higher elevation.

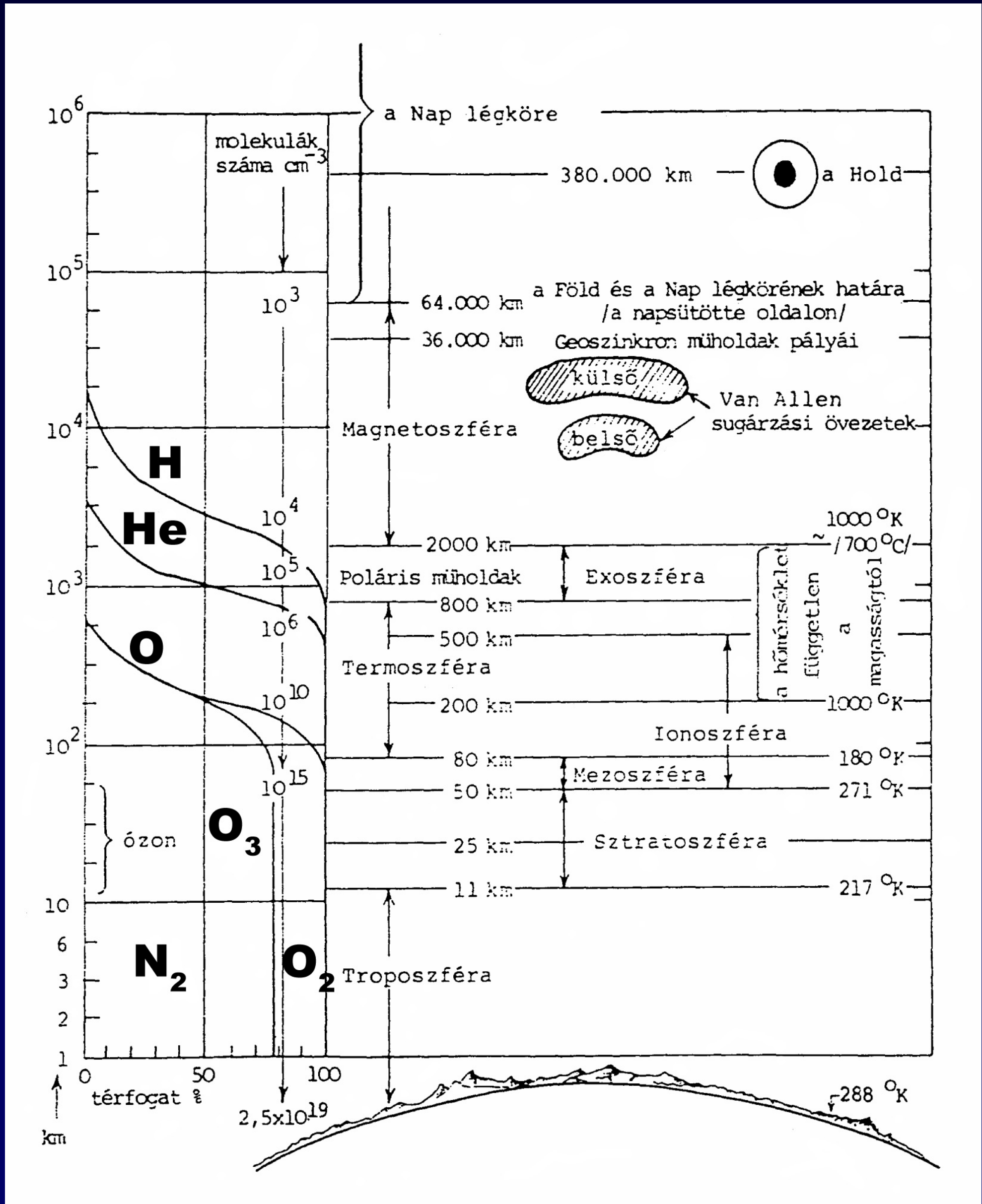
- Stratopause
  - ✓ h ≈ 50 km;
  - ✓ air pressure ≈ 1 hPa;
  - ✓ 0.1% of the total mass of the atmosphere is above it;
- Mezosphere
  - ✓ 50 km < h < 85 km;
  - ✓ small amount of ozone;
  - ✓ negative temperature gradient;
  - ✓ the coldest range of the atmosphere: $t_{85\ km} = -95°C$;
  - ✓ noctilucent clouds;

    - ➢ Why is the mezosphere so cold?
      - ➢ the stratosphere is heated by the ozone layer;
      - ➢ the thermosphere is heated by atoms accelerated by the solar radiation;

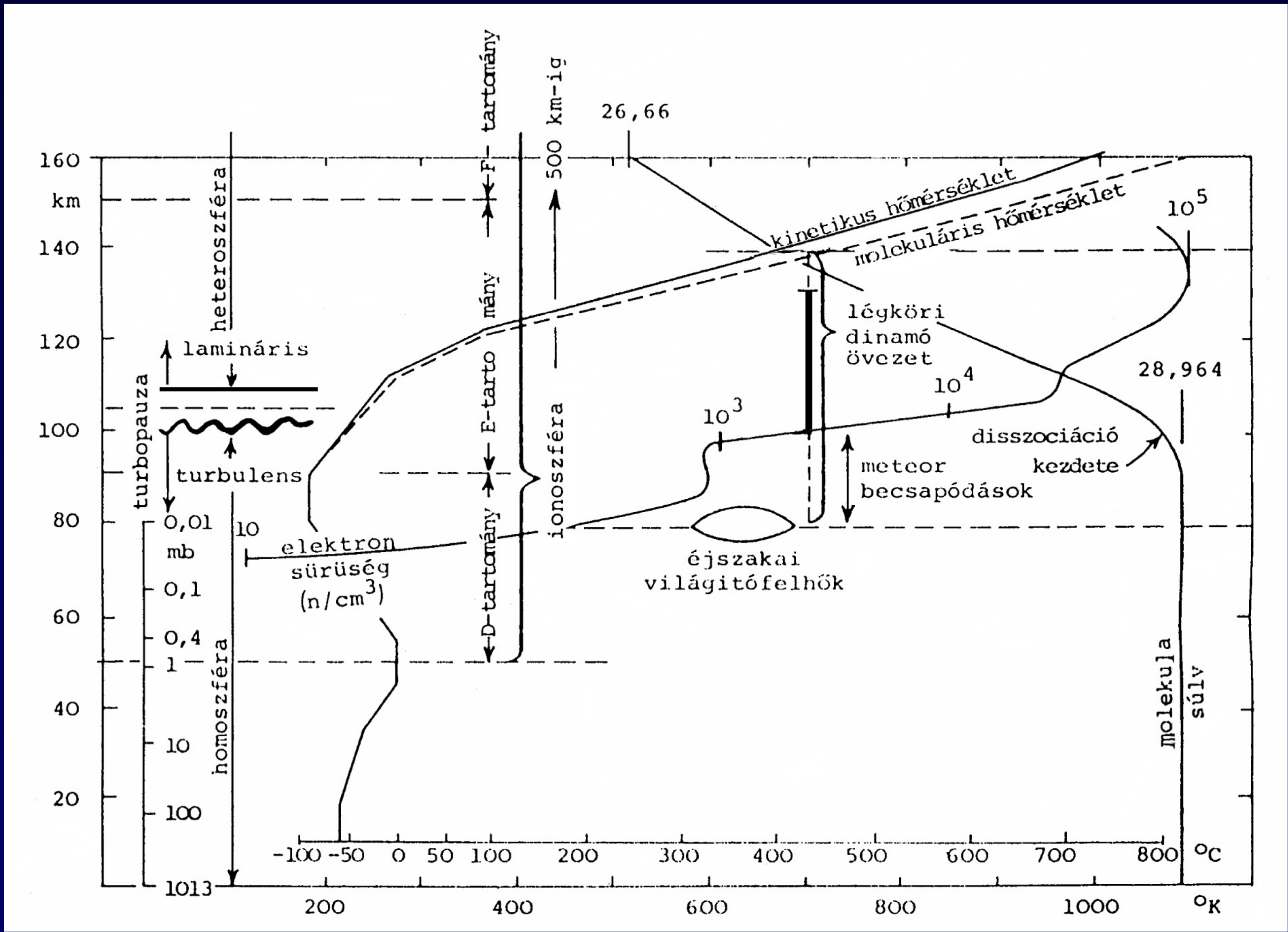
      ⇒ The mezosphere is wedged between two warm layers;

- Mezopause
  - ✓ ~ 85 km
- Thermosphere
  - ✓ the upper limit from the surface:
    85 km < h < 500 km;
  - ✓ the molecules absorb solar radiation
    (high energy photons)
  - ✓ the temperature increases;
  - ✓ air density is very low
    (mean free path length:
    here: 1-10 km,
    at sea level: 10^{-6} cm);

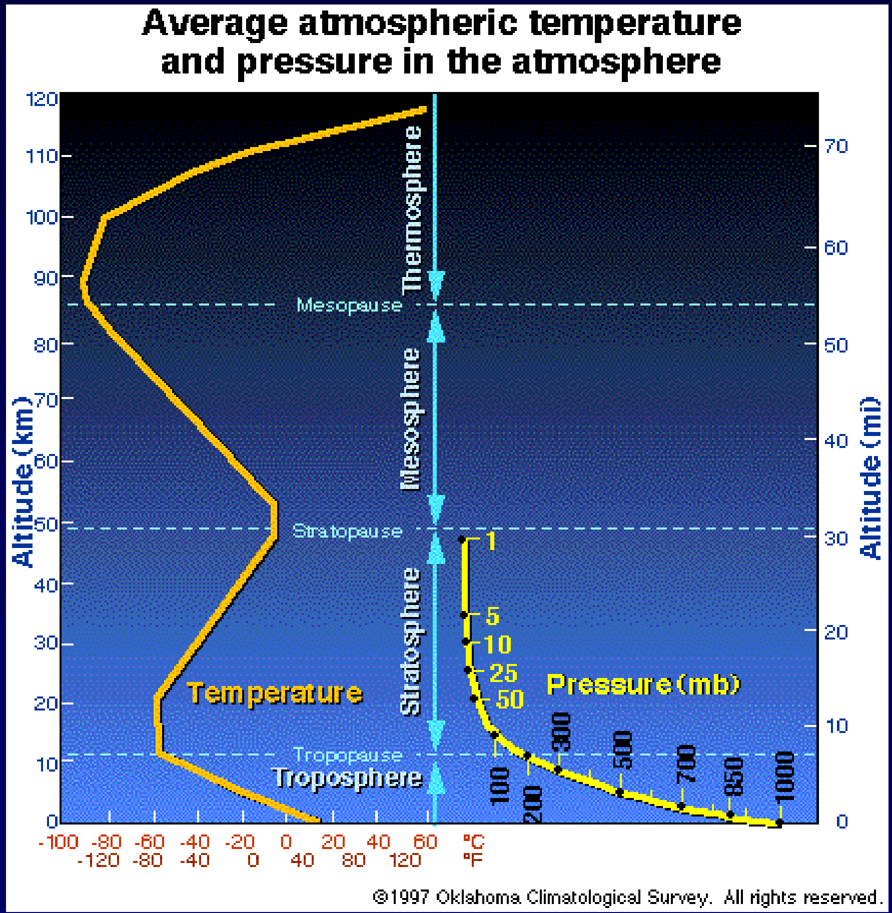
Vertical structure of the atmosphere

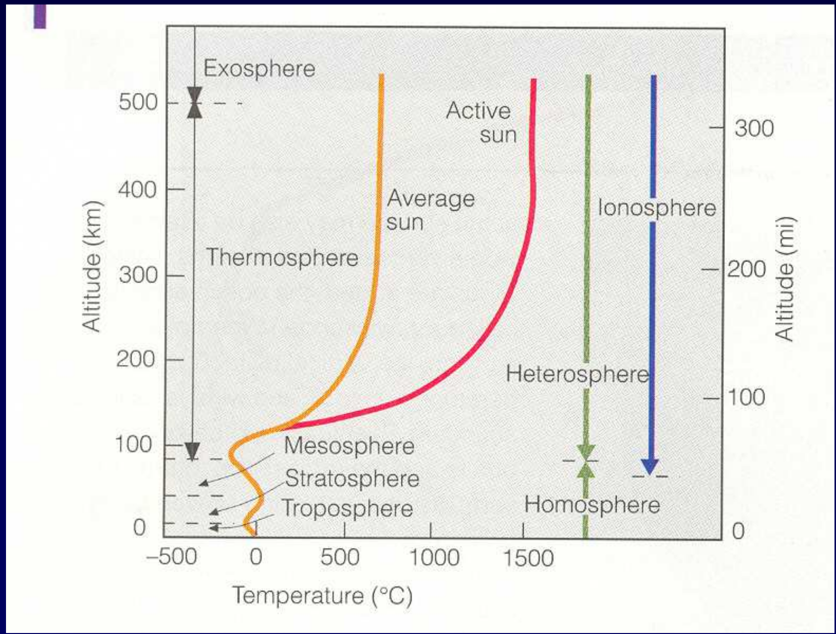


Stratification of the atmosphere, 0 km < h < 160 km



Mean atmospheric temperature, pressure, structure,





Mean temperature, pressure and density, $\varphi = 15^{o}$N

height (km)	air pressure (hPa)	temperature (°C)	density (kgm^{-3})
0	1013.25	15.0	1.225
5	559.0	-2.5	$7.20 \cdot 10^{-1}$
10	285.0	-36.2	$4.20 \cdot 10^{-1}$
20	56.0	-66.4	$9.52 \cdot 10^{-2}$
30	12.2	-40.9	$1.83 \cdot 10^{-2}$
40	3.0	-19.2	$4.18 \cdot 10^{-3}$
50	0.85	-3.0	$1,.10 \cdot 10^{-3}$
60	0.24	-20.0	$3.29 \cdot 10^{-4}$
70	0.058	-54.3	$9.21 \cdot 10^{-5}$
80	0.011	-88.4	$2.09 \cdot 10^{-5}$
90	0.0017	-96.1	$3.38 \cdot 10^{-6}$
100	0.00029	-82.4	$5.15 \cdot 10^{-7}$

We finished for today, goodbye!

ямарваа нэг зүйлийн гэгээлэг талыг нь үргэлж олж харцгаая

өнөөдөртөө ингээд дуусгацгаая, баяртай

让我们总是从光明的一面来看待事物吧！

今天的课程到此结束，谢谢！

دعونا ننظر دائما إلى الجانب المشرق من الأشياء!

انتهينا لهذا اليوم، وداعا!